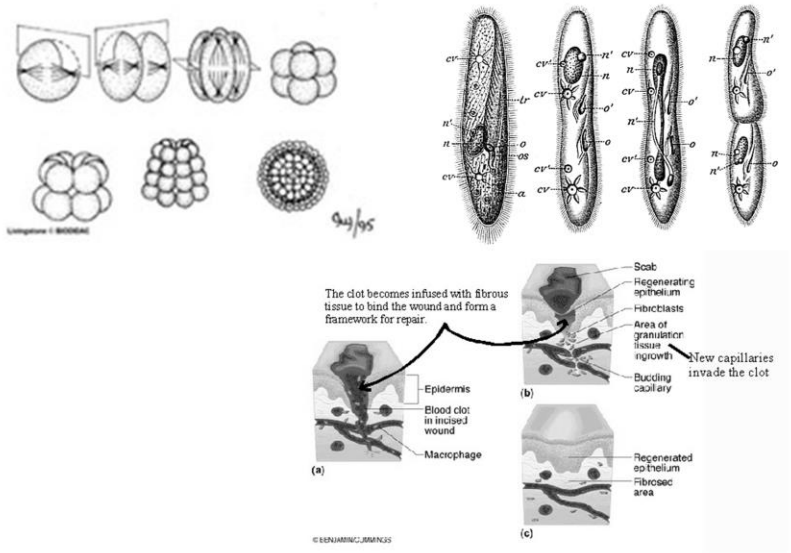
Unit 3.2 - Cell Division & Heredity

AP Biology

Mrs. Petrov

Purposes of Cell Division



1. Large cells not efficient

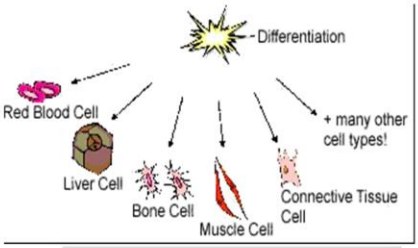
2. Organism reproduction

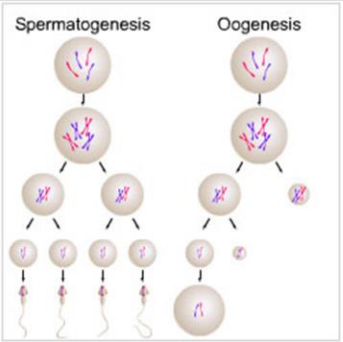
3. Growth

4. Repair & Renewal

2 Cell Types

- Somatic Cells
  - Produced by MITOSIS
  - Diploid (2n)
    - 2 sets of chromosomes
- Reproductive Cells
  - Produced by MEIOSIS
  - Haploid (n)
    - 1 set of chromosomes





Why do you have 2 sets of chromosomes?

Is the information the same from one set to another? (i.e. we have 23 sets…do they all have the same instructions?)

Is the information on each of your sets of chromosomes the same? (i.e. is the information on both copies of chromosome 1 the same?)

Mitosis

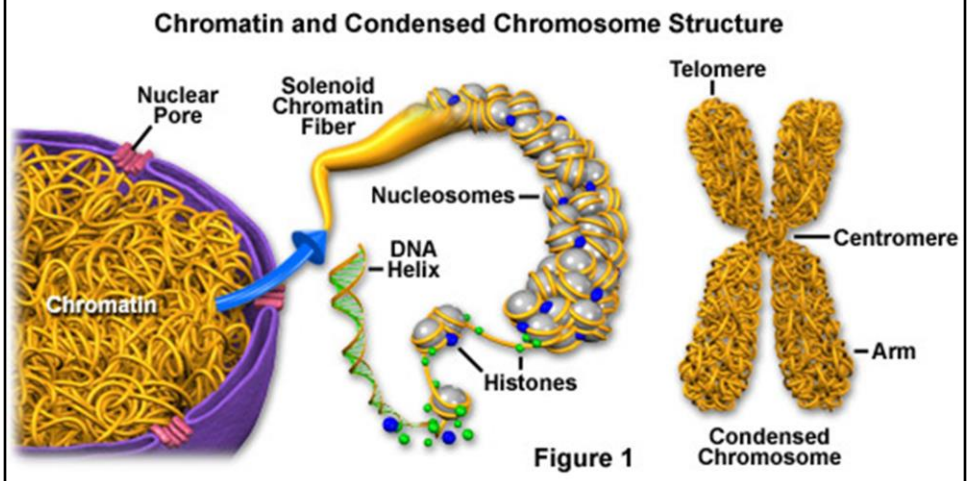
- Goal: To create a GENETICALLY IDENTICAL copy of a cell.
  - The entire genome is duplicated
  - Duplicated chromosomes partitioned equally
  - The cell splits
  - 1 cell becomes 2 cells, 2 cells become 4 cells
  - All cells end up diploid clones of the parent cell in most cases

Meiosis

- Goal: To create sex cells that are genetically diverse from one another.

- The entire genome is duplicated
- Duplicated chromosomes align as homologous pairs
- Homologous pairs cross-over and then separate
- The cell splits
- Each cell then proceeds through another round of division without DNA replication
- 1 cell becomes 2, 2 cells split creating 4 genetically distinct haploid cells.

DNA Organization



Chromatin: All of an organism's DNA in an uncondensed, loose mass.
Seen during times of normal functions, not during division.

Chromosomes: All of an organism's DNA in condensed, tight bunches.
Seen during times of cell division.

Centromere: Area where a chromosome is constricted. Location that chromatids attach to each other.

These words can be confusing, be sure to know the differences!

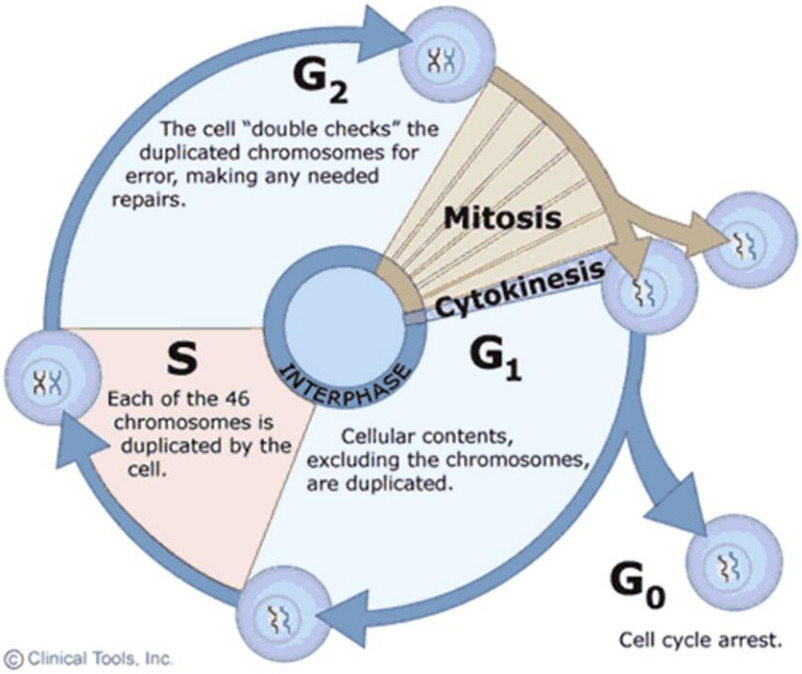
Chromosome:
Condensed DNA after duplication & also after separation by mitosis

Chromatid (sister chromatid):
Half of a duplicated chromosome
A duplicated chromosome has 2 chromatids

1. If there are 20 chromatids in a cell, how many centromeres are there?
   a. 10
   b. 20
   c. 30
   d. 40

2. A scientist takes tissue samples from mammalian ovaries & testes. Which of the following best describes their expected findings?
   a. Haploid cells only
   b. Diploid cells only
   c. Both haploid & diploid cells
   d. Cells that were all genetically identical to each other

The Cell Cycle



This is a CYCLE: Knowing where in the cycle a cell is helps for remembering what comes next and what is required for it to happen.

Interphase: Growth, DNA synthesis, preparation for division.

Mitotic phase (M phase)

Mitosis/Meiosis: Partitioning of DNA into each cell

Cytokinesis: Division of cytoplasm

Interphase

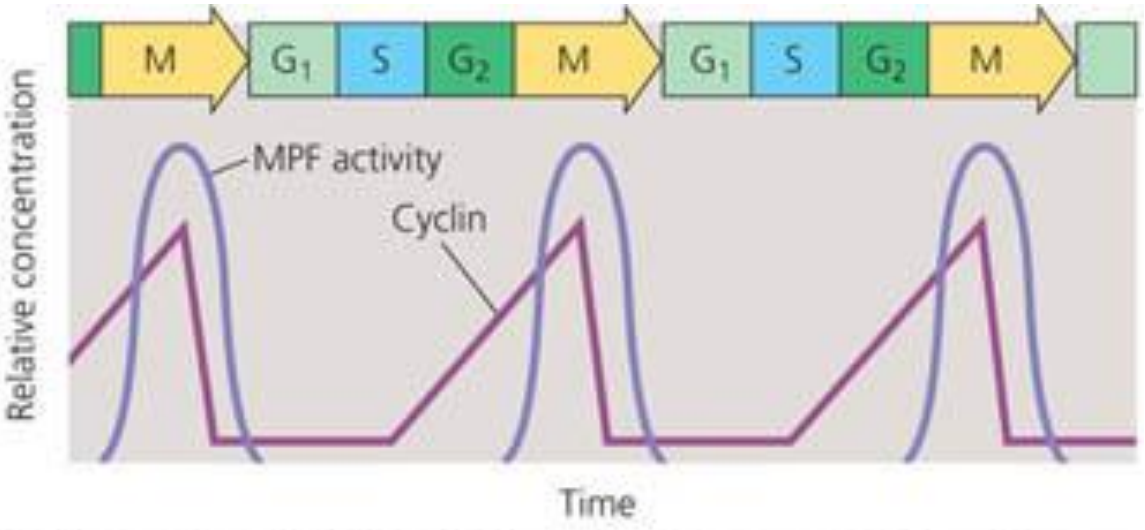
- G1 Phase – Cell grows and produces proteins, extra organelles.
  - Regulated at the G1 checkpoint by proteins called **cyclins**.
  - If passed, cell usually continues the rest of the cycle.
  - If not passed, cell enters G0 phase. The cell essentially exits the division phase and can "try again later" or will not divide for its duration.
    - Nerve Cells - Muscle cells

Interphase

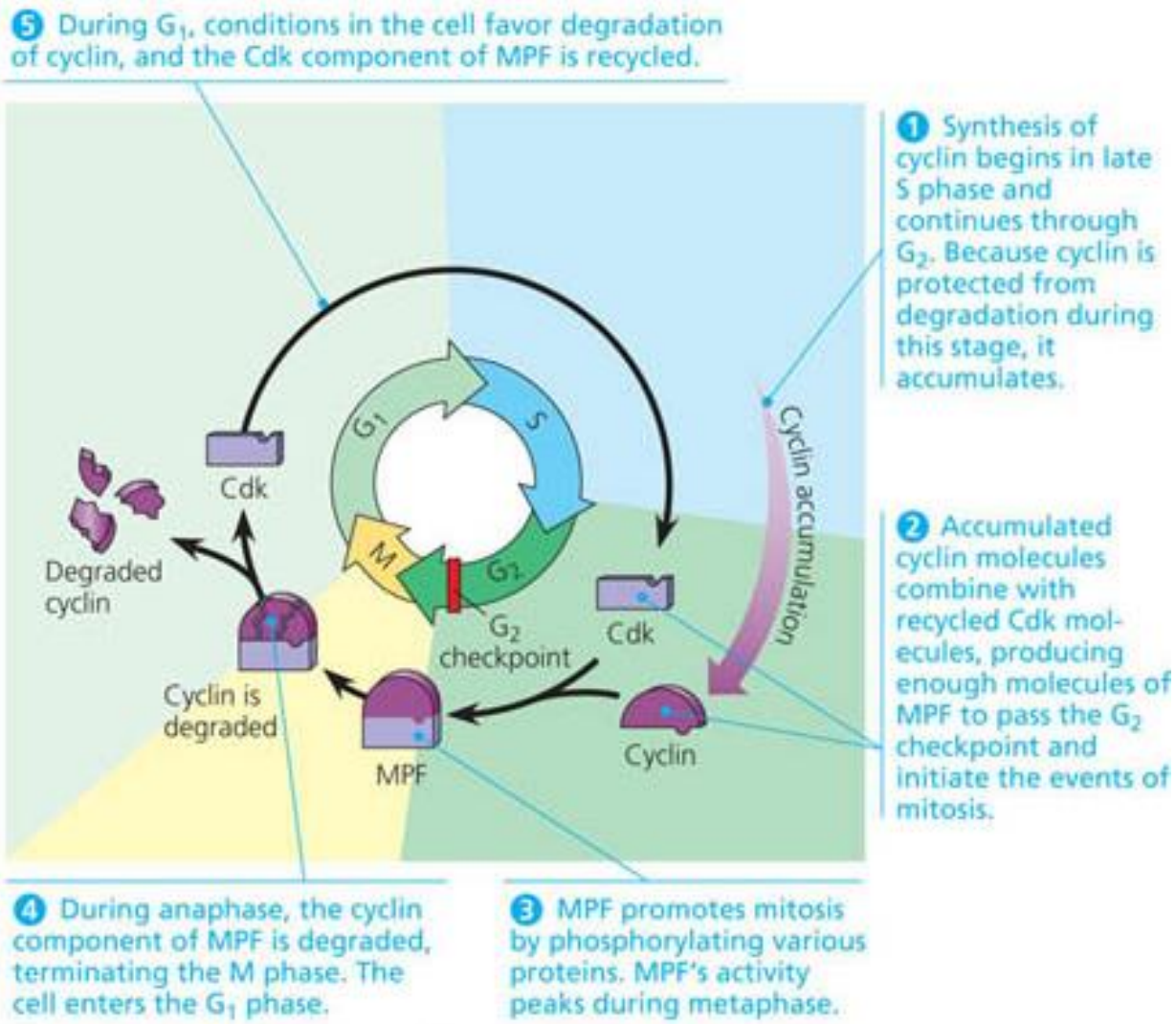
- S Phase – "Synthesis" Phase
  - DNA is duplicated
  - Point at which all the chromatin has doubled in quantity

Interphase

- G2 Phase – Cell grows and produces proteins, extra organelles.
  - Regulated at the G2 checkpoint by proteins called **cyclins**.
  - Specific regulating factor is called **MPF**
    - M-phase Promoting Factor
- Remember: DNA has doubled!



(a) Fluctuation of MPF activity and cyclin concentration during the cell cycle



(b) Molecular mechanisms that help regulate the cell cycle

Loss of Control

- Cancer cells: Cells that have overcome the control of the cell cycle.
- Example: **Gene Amplification** of Cyclin D
  - Leads to overproduction of Cyclin D, causing the cells to constantly divide.
  - Possible reasons why DNA is *continuously* transcribed & translated (expressed):
    - "Stress"?
    - Carcinogenic chemicals?

Cancers can be caused by ANY factor that disrupts normal cell division, leading to the large variety of cancer types.

Certain factors such as genetics or carcinogens can increase risk of disruptions, but in the end any cell has the potential to become cancerous without anything someone did or didn't do.

1. Measurements of the amount of DNA per nucleus were taken on a large number of cells from a growing fungus. The measured DNA levels ranged from 3 to 6 picograms per nucleus. In which stage of the cell cycle did the nucleus contain 6 picograms of DNA?

   A) G0

   B) G1

   C) S

   D) G2

2. A group of cells is assayed for DNA content immediately following mitosis and is found to have an average of 8 picograms of DNA per nucleus. How many picograms would be found at the end of S and the end of G2?

   A) 8; 8

   B) 16; 16

   C) 16; 8

   D) 8; 16

3. You have the technology necessary to measure each of the following in a sample of animal cells: chlorophylls, organelle density, picograms of DNA, cell wall components, and enzymatic activity. Which would you expect to increase significantly from M to G1?

   A) organelle density and enzymatic activity

   B) cell wall components and DNA

   C) chlorophyll and cell walls

   D) organelle density and cell walls

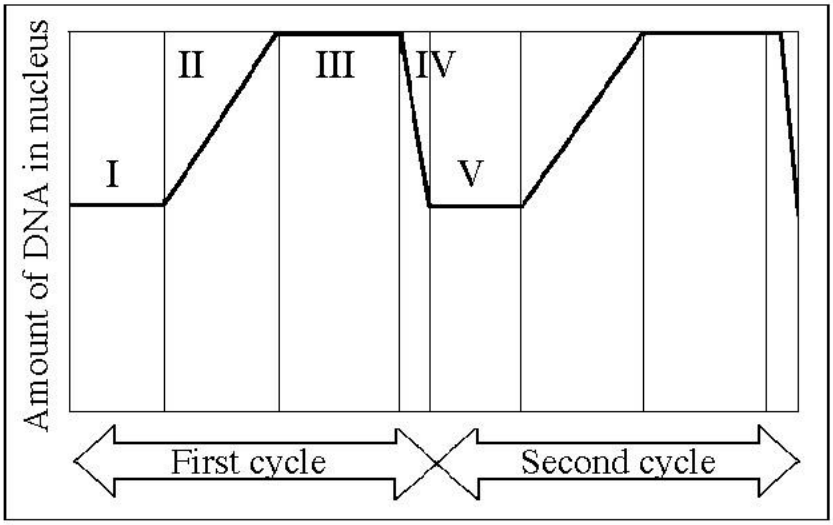
4. A particular cyclin called cyclin E forms a complex with Cdk 2 (cyclin-dependent kinase 2). This complex is important for the progression of the cell from G1 into the S phase of the cell cycle. Which of the following statements is correct?

   A) The amount of free cyclin E is greatest during the S phase.

   B) The amount of free Cdk 2 is greater during G1 compared to the S phase.

   C) The amount of free cyclin E is highest during G1.

   D) The amount of free Cdk 2 is greatest during G1.



5. In the figure above, mitosis is represented by which numbered part(s) of the cycle?

A) I

B) II

C) III

D) IV

6. G1 is represented by which numbered part(s) of the cycle?

A) I or V

B) II or IV

C) III only

D) IV only

7. Which number represents the point in the cell cycle during which the chromosomes are replicated?

A) I

B) II

C) III

D) IV

8. At which of the numbered regions would you expect to find cells at metaphase?

A) I and IV

B) II only

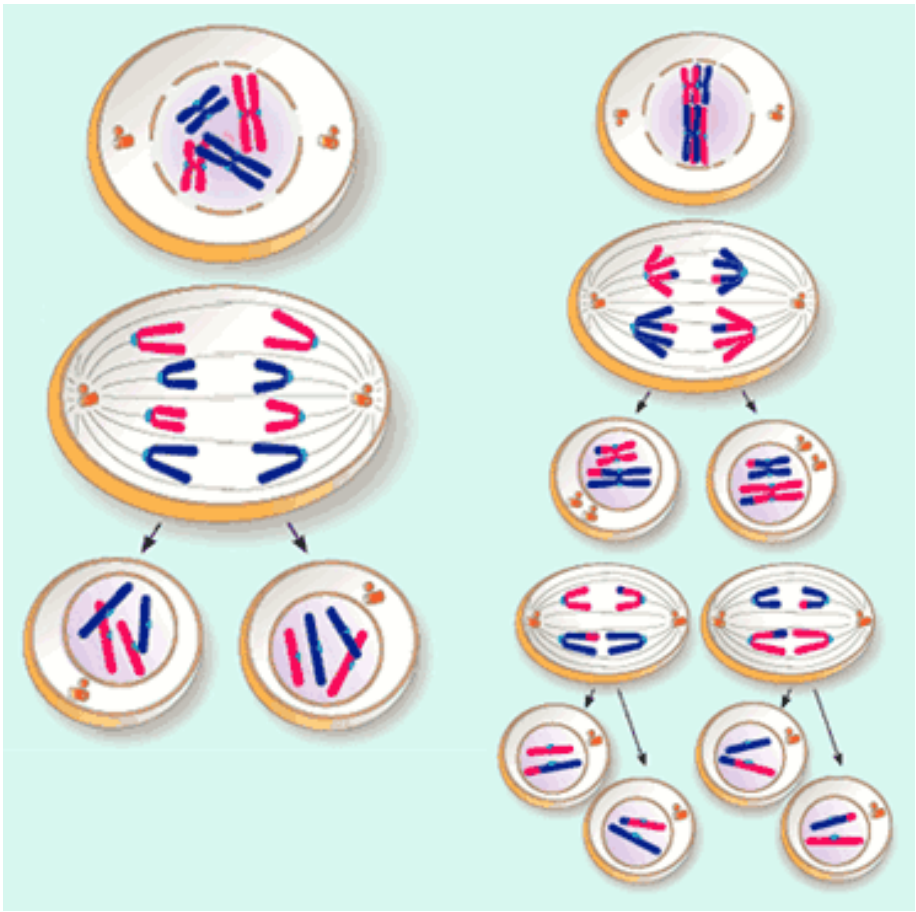
C) III only

D) IV only

M Phase

Mitosis or Meiosis followed by Cytokinesis

Mitosis **Meiosis**



Mitosis & Meiosis

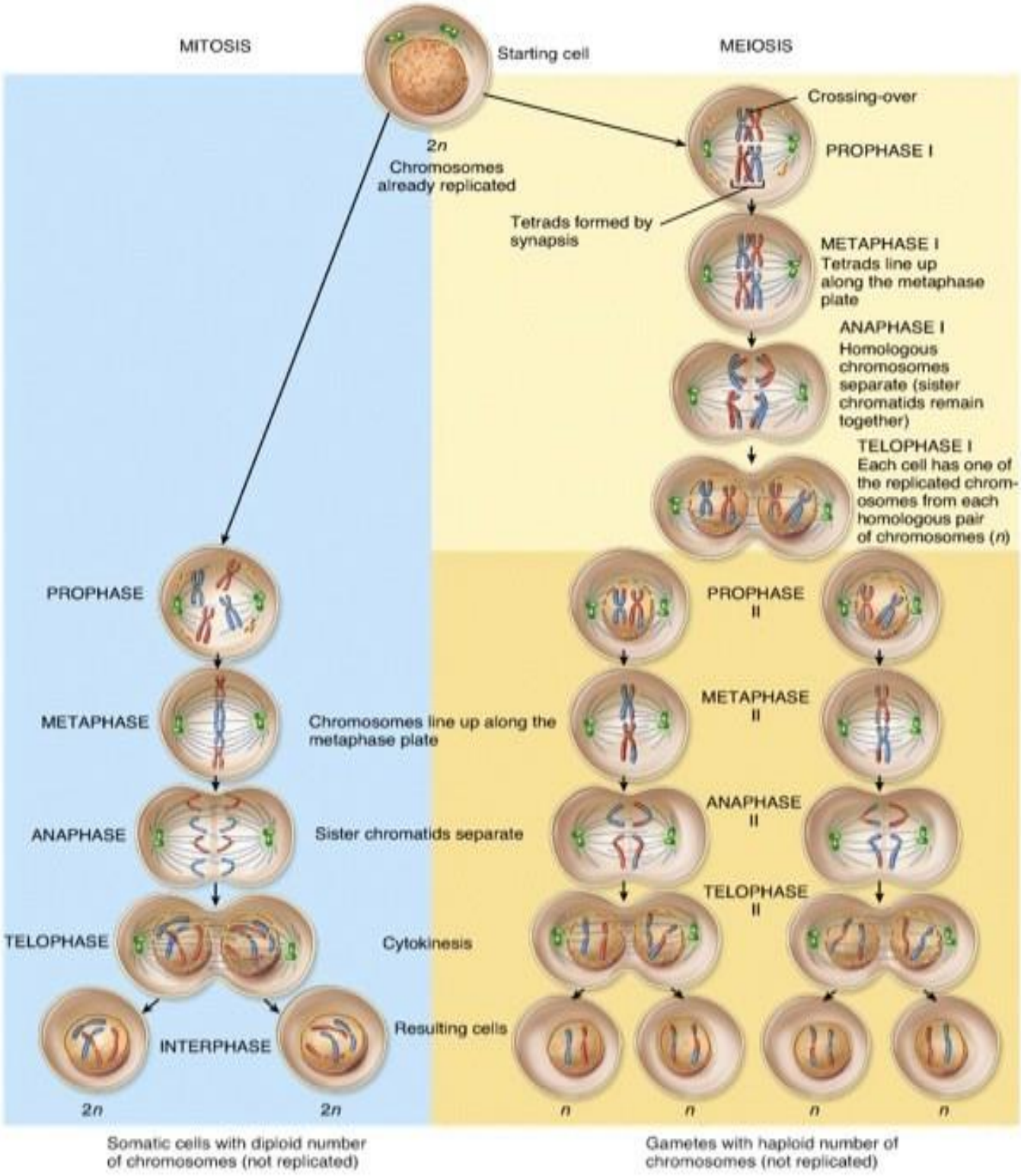
- Both cell divisions require 1 initial DNA replication.
- Both cell divisions require a separation of genetic material to be partitioned into the splitting cell.
- Both cell divisions require a complex network of protein microtubules to direct chromosome separation.
- Both cell divisions require a complex mechanism of splitting the cytoplasm/cell.

Mitosis Only

- Daughter cells genetically identical to each other & parent cell.
- 1 Division results in 2 cells.
- Duplicated chromosomes align in a single row before separating.
- Chromosomes do not interact with each other.

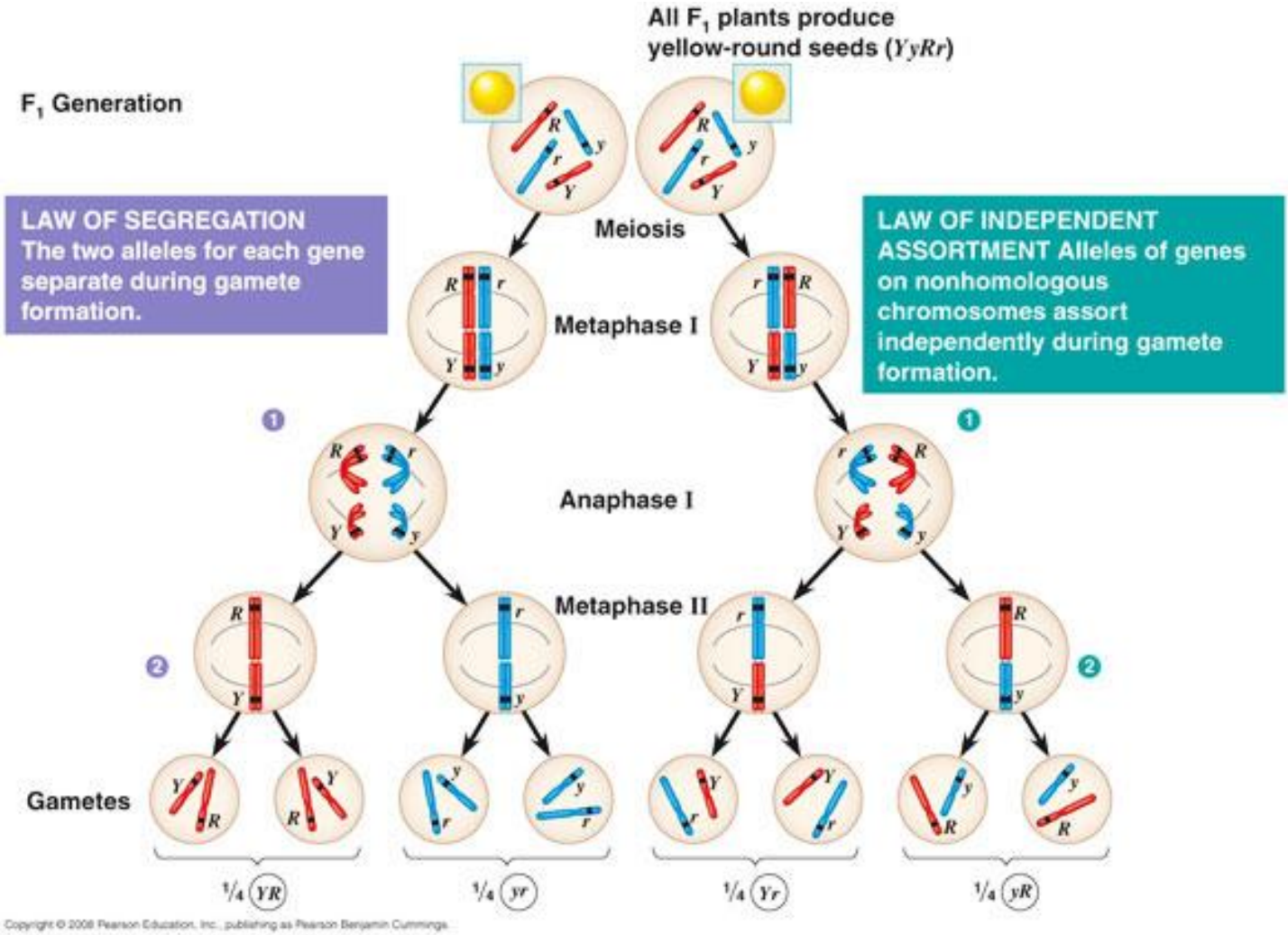
Meiosis Only

- Daughter cells genetically different from each other & parent cell
- 2 divisions result in 4 cells.
- Duplicated chromosomes align in homologous pairs before 1st division.
- Homologous chromosome pairs cross over with each other.


MITOSIS
Starting cell
MEIOSIS
2n
Chromosomes already replicated
Crossing-over
PROPHASE I
Tetrads formed by synapsis
METAPHASE I
Tetrads line up along the metaphase plate
ANAPHASE I
Homologous chromosomes separate (sister chromatids remain together)
TELOPHASE I
Each cell has one of the replicated chromosomes from each homologous pair of chromosomes (n)
PROPHASE
METAPHASE
Chromosomes line up along the metaphase plate
ANAPHASE
Sister chromatids separate
TELOPHASE
Cytokinesis
INTERPHASE
Resulting cells
2n
2n
PROPHASE II
METAPHASE II
ANAPHASE II
TELOPHASE II
n
n
n
n
Somatic cells with diploid number of chromosomes (not replicated)
Gametes with haploid number of chromosomes (not replicated)

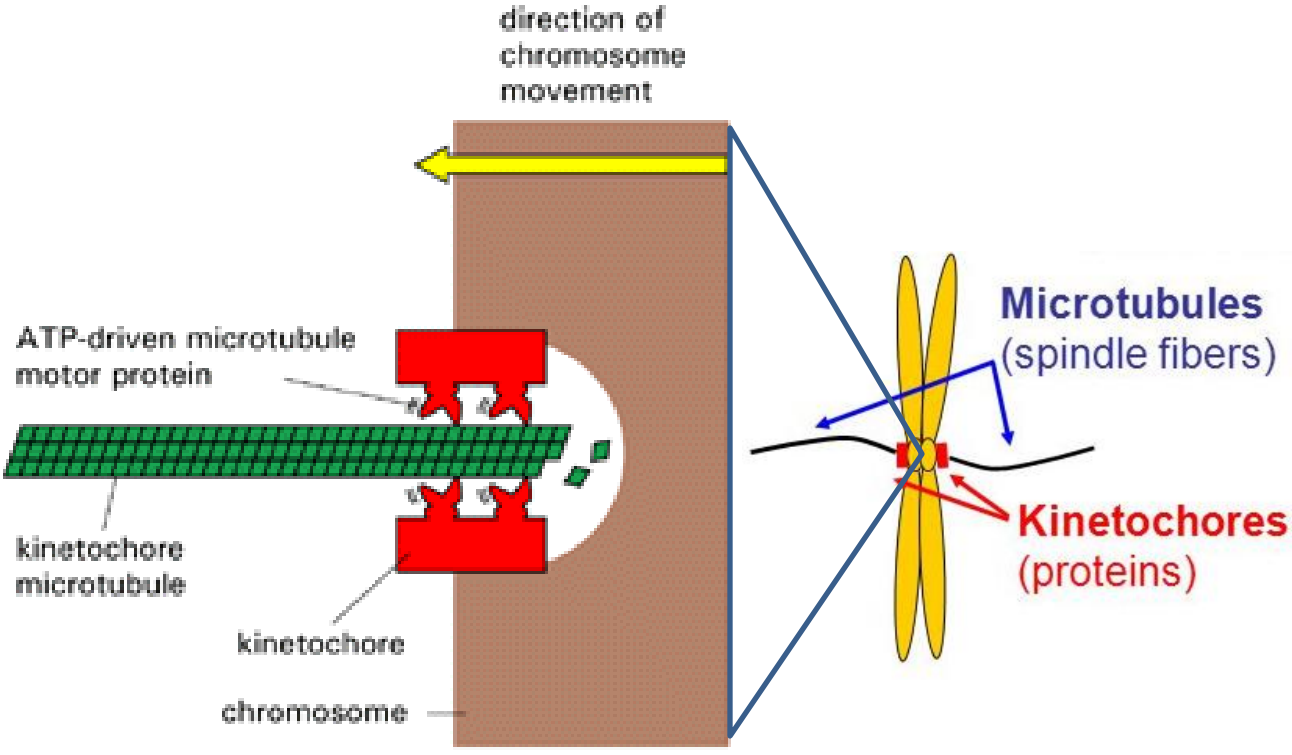
How genetic diversity results from Meiosis

1. Crossing over during Prophase
2. Alignment during Metaphase
3. Separations during Anaphase



Chromosome Separation

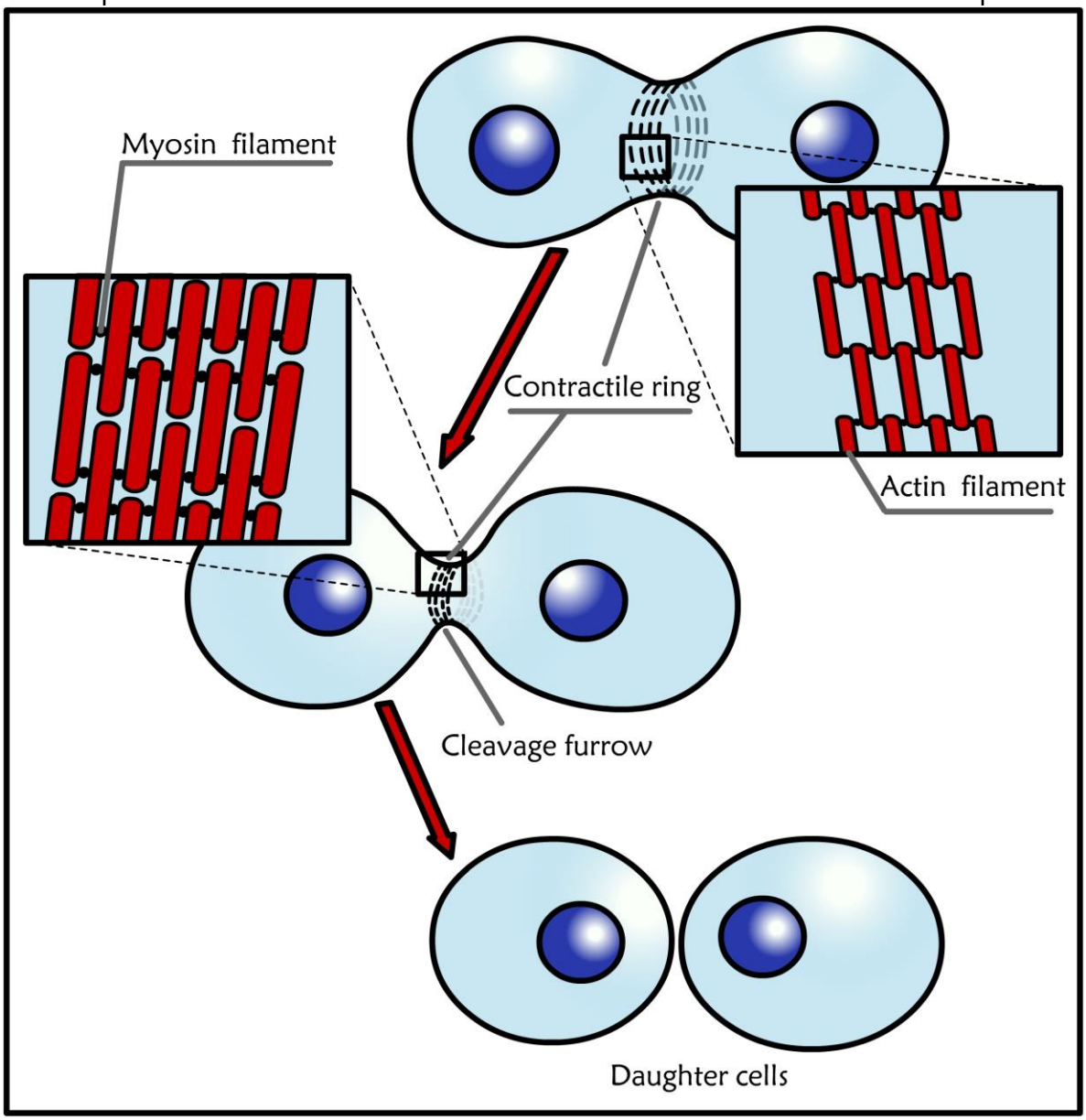
- Kinetochore region of centromere digests microtubule protein, shortening it.
- ATP powers motor proteins that pull the chromosome away from digestion site.
- Overall outcome is the chromosomes move to opposite ends of the cell.



(A) ATP-driven chromosome movement drives microtubule disassembly

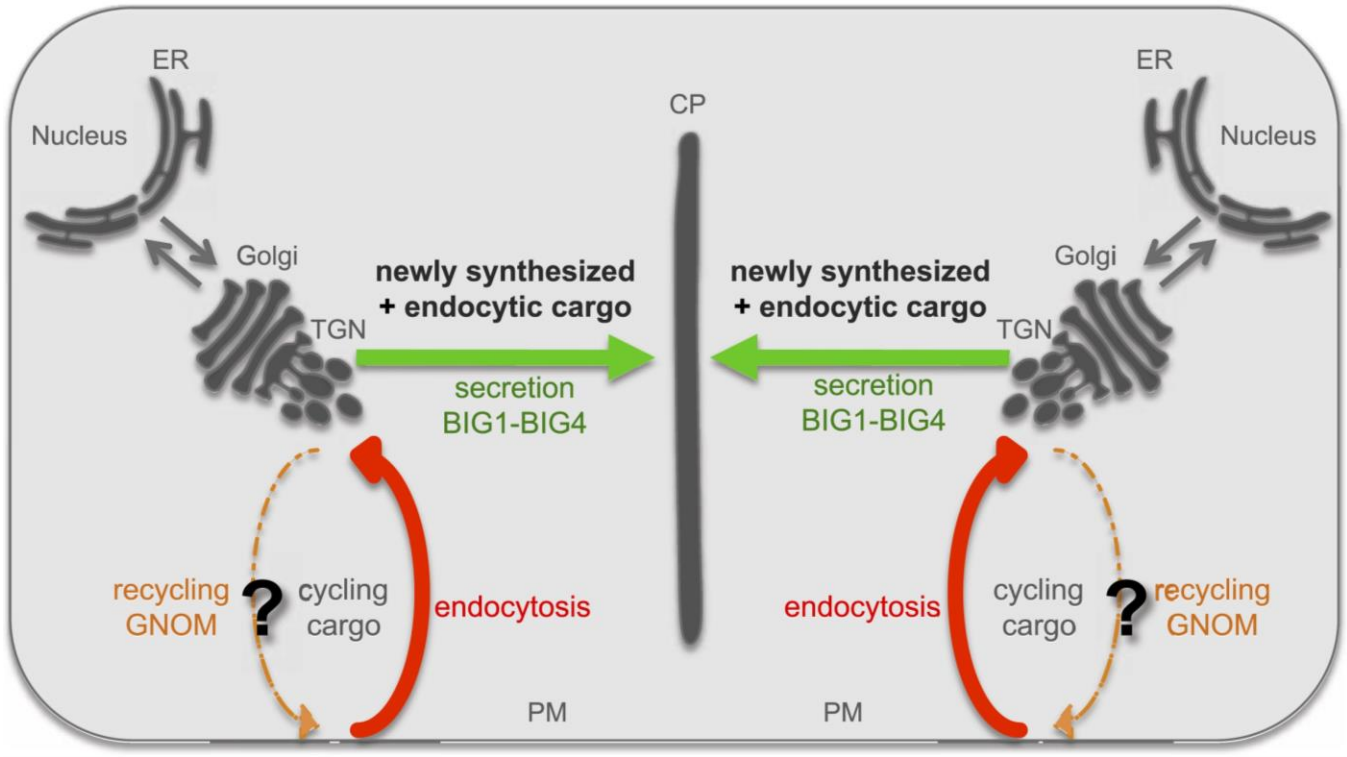
Animal Cytokinesis

- ATP powers Actin & Myosin motor protein contractions in center of the cell.
- Contractions cause the cell to pinch in the center, eventually splitting into 2 cells.



Plant Cytokinesis

- Golgi secretes proteins making up a cell plate.
- Cell plate grows in center of cell until fusing with pre-existing cell membrane/wall.



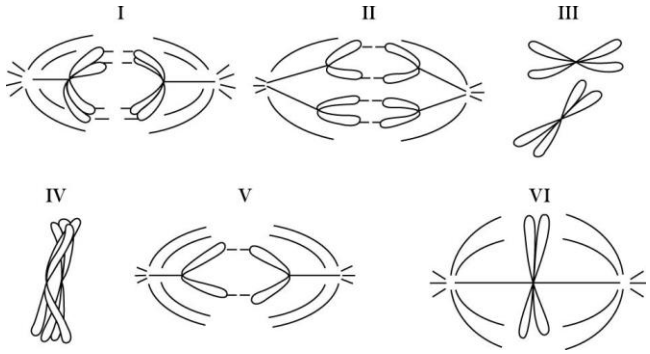
1. If cells in the process of dividing are subjected to colchicine, a drug that interferes with the formation of the spindle apparatus, at which stage will mitosis be arrested?

A) anaphase

B) prophase

C) telophase

D) metaphase



2. Which diagram above represents anaphase I of meiosis?

A) I

B) II

C) IV

D) V

3. Which diagram above could represent anaphase of mitosis or meiosis?

A) I only

B) II only

C) II & IV

D) I, II, & IV

4. Which diagram above represents a phase that can produce genetic diversity?

A) IV only

B) I & IV only

C) I, II & V only

D) All except III

5. Which of the following are primarily responsible for cytokinesis in plant cells but not in animal cells?

A) kinetochores

B) Golgi-derived vesicles

C) actin and myosin

D) centrioles and centromeres

6. Movement of the chromosomes during anaphase would be most affected by a drug that

A) prevents shortening of microtubules.

B) reduces cyclin concentrations.

C) prevents elongation of microtubules.

D) prevents attachment of the microtubules to the kinetochore.

7. Which of the following best describes how chromosomes move toward the poles of the spindle during mitosis?

A) The chromosomes are "reeled in" by the contraction of spindle microtubules.

B) Motor proteins of the kinetochores move the chromosomes along the spindle microtubules.

C) Non-kinetochore spindle fibers serve to push chromosomes in the direction of the poles.

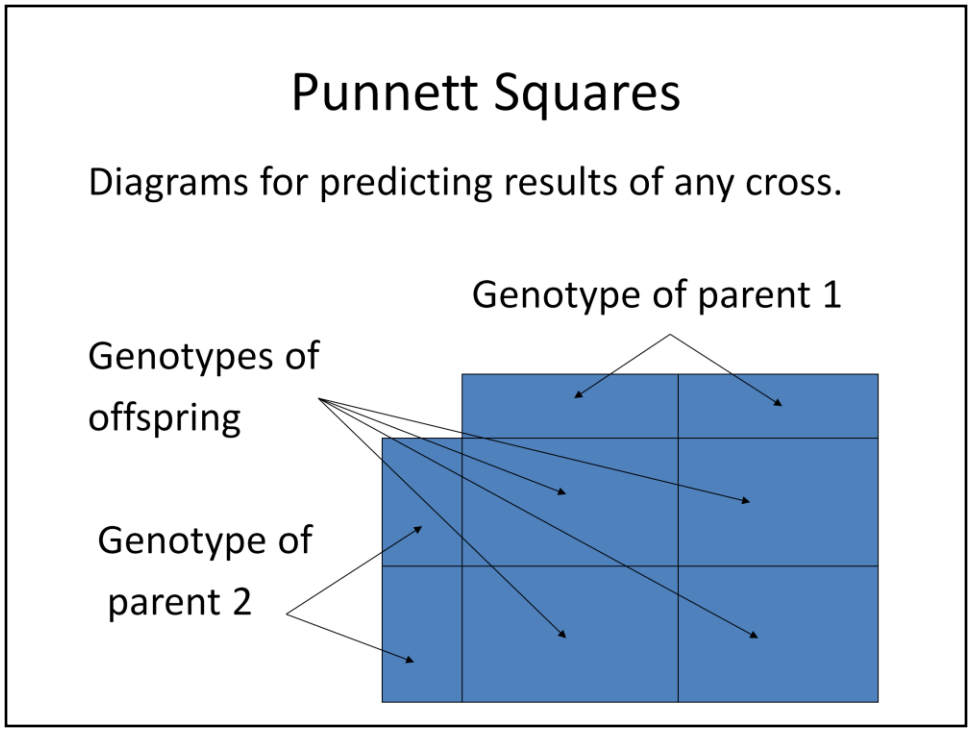
D) The chromosomes are "reeled in" by the contraction of spindle microtubules, and motor proteins of the kinetochores move the chromosomes along the spindle microtubules.

DNA Transmissions from Parents to Offspring: Heredity

Laws Governing Outcomes

Law of Segregation: Alleles found on non-homologous chromosomes sort out independent of each other during meiosis. (Ex. -The genes on chromosome pair 1 don't depend on the genes on chromosome 18)

Law of Independent Assortment: Homologous chromosomes align with each other but their orientations vary in terms of which allele face where and thus will end up in combination with other distinct alleles.



The Punnett square predicts how they could turn out based on laws of segregation & independent assortment.

Term review:

1. Homozygous dominant – 2 copies of dominant allele
2. Homozygous recessive – 2 copies of recessive allele
   - *Both Also known as <u>TRUE BREEDING/PURE BREED</u>*
3. Heterozygous – 1 copy of each allele
4. P-generation – the parental generation
5. F1 generation – offspring of parental mating
6. F2 generation – offspring of F1 mating
7. Test-Cross – Crossing a homozygous recessive with an unknown genotype
8. Genotypic Ratios – Ratios of each genotype from a cross
9. Phenotypic Ratios – Ratios of each phenotype from a cross

Dominance

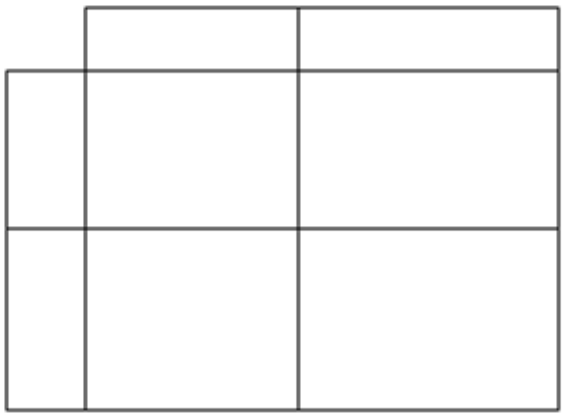
Many traits follow simple dominant/recessive patterns.

One allele is dominant & other allele is recessive.

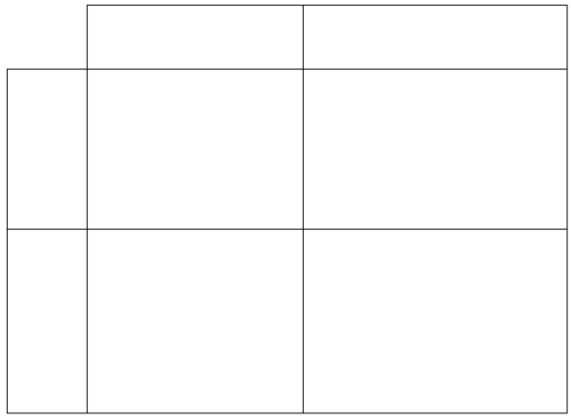
The dominant allele will determine the phenotype if present.

Recessive phenotypes only present if dominant allele is absent.

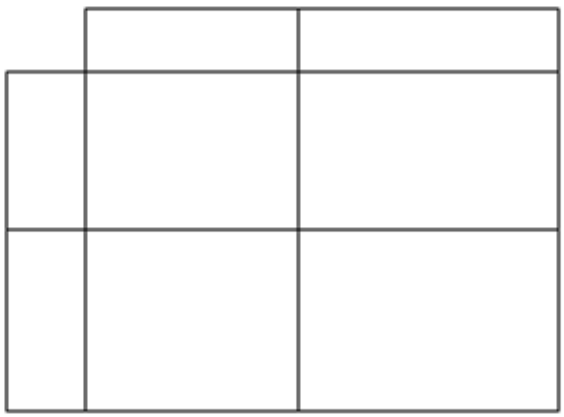
Single Trait Cross



Single Trait Cross



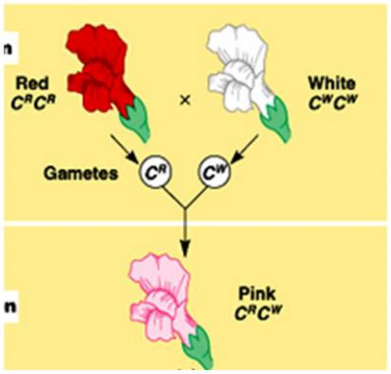
Single Trait Cross



Alternate Dominance Patterns

Simple rules of dominant/recessive don't always hold true.

1. **Incomplete dominance:**
   Both alleles present = Intermediate



2. Codominance:

Both alleles present = Both appear

Brown & White both dominant = both colors appear

Mixed Inheritance

3. Multiple alleles:

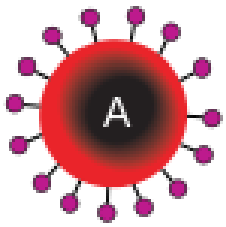
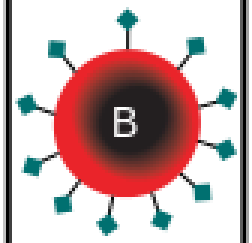
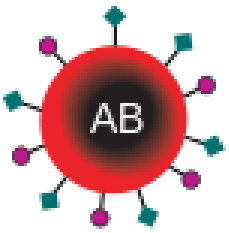
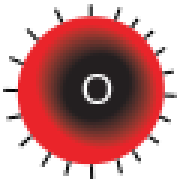
More than 2 alleles for 1 gene

Blood Groups

Allele combination	Blood type
I^AI^A or I^AI^O	A
I^BI^B or I^BI^O	B
I^AI^B	AB
I^OI^O	O

I^O is sometimes written as "i"

ii = O, I^Ai = A, etc.

	Group A	Group B	Group AB	Group O
Red blood cell type				
Antibodies in Plasma	 Anti-B	 Anti-A	None	 Anti-A and Anti-B
Antigens in Red Blood Cell	A antigen	B antigen	 A and B antigens	None

Sex-Linked Genes

Males = 44, Y X

a. All X-linked traits will be expressed in males.
   Only 1 X chromosome, so either YES or NO!

Females = 44, X X

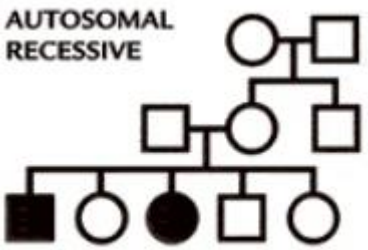
a. If trait is dominant, it will be expressed if 1 copy is present.
b. If trait is recessive, it will be expressed if present on BOTH X chromosomes.

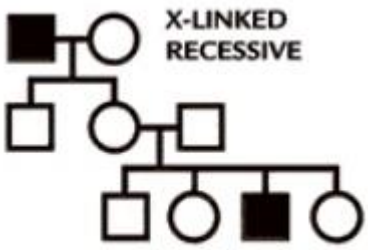
Sex Chromosomes

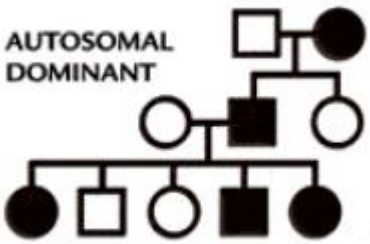
Sperm = X or Y Egg = X only

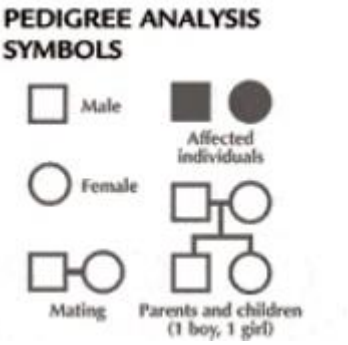
		Female: X	Female: X	
Male	X	XX	XX	50% female
	Y	XY	XY	50% male

Pedigree Analysis









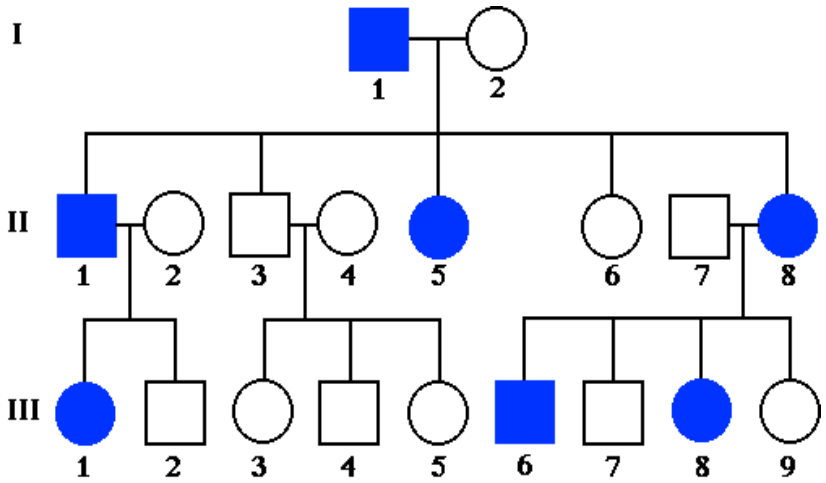
	Autosomal Dominant	Autosomal Recessive	X-Linked Recessive
% of Offspring Affected	50% if 1 heterozygous parent and one unaffected parent 75% if 2 heterozygous affected parents 100% if 1 homozygous affected parent	0% if 1 carrier parent and 1 parent homozygous unaffected 25% if 2 heterozygous carrier parents 50% if 1 homozygous affected parent and 1 heterozygous carrier parent	0% of sons if dad is affected 50% of sons if mom is a carrier 100% of sons if mom is affected
Male & female offspring effected at the same rate?	Yes	Yes	No (males affected much more often)
Allele Inherited From which parent(s)?	Either	Either	Sons = Mom only Daughters = Either
Can be inherited from unaffected parents?	No	Yes	Yes

1. Cystic Fibrosis is an autosomal recessive disorder. A man without CF & a woman with CF have a child with CF. Which of the following was likely true of the parents?
    a. The mother was homozygous dominant and the father was homozygous recessive.
    b. The father was pure breeding and he mother was a heterozygote.
    c. The mother was homozygous recessive and the father was a heterozygote.
    d. The mother was a homozygous recessive and the father was homozygous dominant.

2. If one of the male children without CF from the family described above has numerous children who never exhibit CF, what it the likely true about these children's' mother?
    a. The mother was heterozygous.
    b. The mother was homozygous dominant.
    c. The mother was homozygous recessive.
    d. The mother was either heterozygous or homozygous dominant.

3. A calico cat (black & orange spotted fur) and a black cat (black fur only) have many kittens. Some female kittens are black & others are calico. Of the males, some are black and others are orange (orange fur only). Which of the following is likely true?
    a. The color black is incompletely dominant over orange & the gene is located on an autosome.
    b. The inheritance pattern cannot be determined by this information.
    c. The colors orange & black are codominant & the gene is located on the X-chromosome.
    d. The colors orange & black are codominant & the gene is located on an autosome.

4. A mother of unknown blood type has children with a man with type O blood. Their children's blood types are: 50% OB & 50% OA. Which of the following is likely true?
    a. Only the father could donate blood to the children.
    b. Only the mother could donate blood to the children.
    c. The mother could receive blood from only the OA children.
    d. The father could receive blood from any child.



5. The diagram above is a pedigree showing inheritance of a trait throughout 3 generations. Squares represent males & circles represent females. Shaded squares or circles represent individuals affected by the trait. Which of the following is likely true?
    a. The trait is autosomal recessive.
    b. The trait is X-linked recessive.
    c. The trait is autosomal dominant.
    d. The trait could be autosomal recessive or dominant.

Statistical Analysis

- Data can be used to test if some alternate form of inheritance is acting, or if some type of influence (environment, another gene, etc.) is acting.
- Observed & expected values will be statistically different.

How do we know the EXPECTED values?

Statistical Analysis

- Example Problem

Round is dominant to wrinkled in pea seeds.

A hybrid cross produced 722 round seeds and 278 wrinkled seeds.

Is this data significant enough to verify the expected inheritance pattern?

Method: Chi square analysis

$X^2 = \Sigma [(o - e)^2 / e)]$

- Σ = sum
- o = observed # individuals
- e = expected # individuals

Statistical Analysis

Find critical value at .05 p value

Probability (p)	Degrees of Freedom (df)				
	1	2	3	4	5
.05	3.84	5.99	7.82	9.49	11.1

Determining the degrees of freedom (df)

- The number of different phenotypes minus 1
- df = _____

Use critical values to analyze results

- IF Chi square value is > or equal to critical value, the **null** hypothesis is **REJECTED**.
  - Meaning… the data are statistically different from expected values.

- IF Chi square value is < the critical value, the **null** hypothesis is **ACCEPTED**.
  -Meaning… The data are not statistically different from expected values.

Two-Trait Crosses

Consider 2 traits for a cross

- Eye color & height
- Blood type & pigment type

Dihybrid Cross

Genotype of parent 1 = **R r D d**

Genotype of parent 2 = **R r D d**

1. **Figure out the combinations for each parents' gametes.**

This is often the most difficult step in 2-trait crosses.

Remember, each possible gamete needs to have a copy of EACH trait...
Or else the gamete ends up with no information to express that trait!

Dihybrid Cross

Genotype of parent 1 = **R r D d**

R + r **X** **D + d**

Use FOIL like in mathematics.

(R + r)	x	(D + d)
Either R/r could End up in the gamete		Either D/d could End up in the gamete

This equation is literally read out as : R -OR- r and D -OR- d will be the alleles present in the gamete.

OR – means add
AND – means multiply

Thus, we end up with the same equation “style” as FOIL.

Dihybrid Cross

Genotype of parent 1 = **R r D d**

Gamete combinations =

R D + R d + r D + r d

-or- -or- -or- -or-

Since any of the 4 combinations could be the genetic information present in the gamete, we have to consider all 4 possibilities!

Remember, these crosses are representing POSSIBILITIES, not actualities!

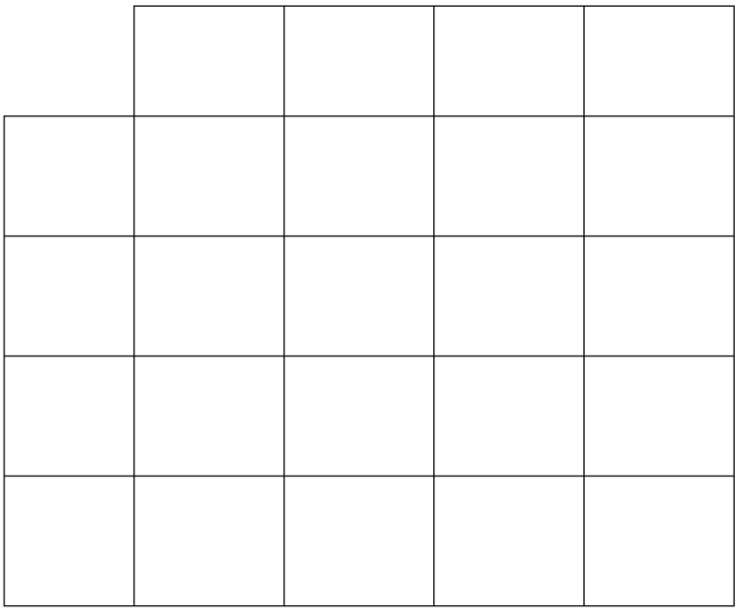
Dihybrid Cross

Genotype of parent 2 = **R r D d**

Same genotype, same gamete combinations =

R D R d r D r d

Dihybrid Cross



What's the probability of having a child with dimples and being left-handed?

Dihybrid Cross

Independent Assortment

a. New allele combinations were made

b. Traits didn't affect *each other*

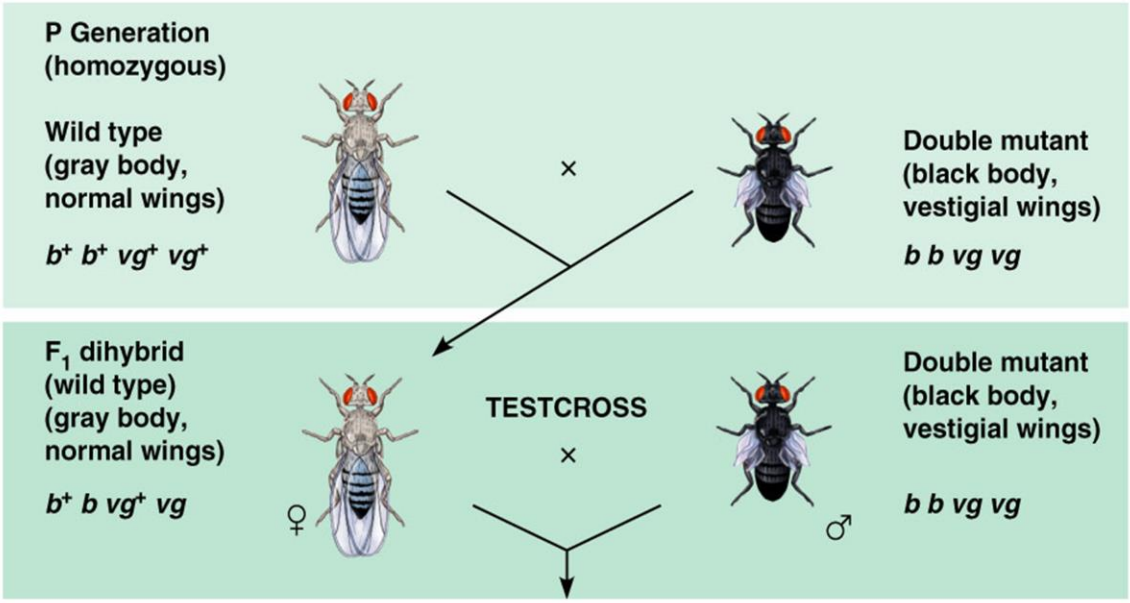
c. Gene for right hand/left hand **independent** from gene for dimples because they are on different chromosomes.

These are called un-linked genes.

Phenotypic Ratio of a dihybrid cross is expected to be: 9:3:3:1

If deviations occur, it is likely that the 2 genes though to be on separate chromosomes are actually *on the same chromosome.*

Thomas Hunt Morgan



Predicted results:

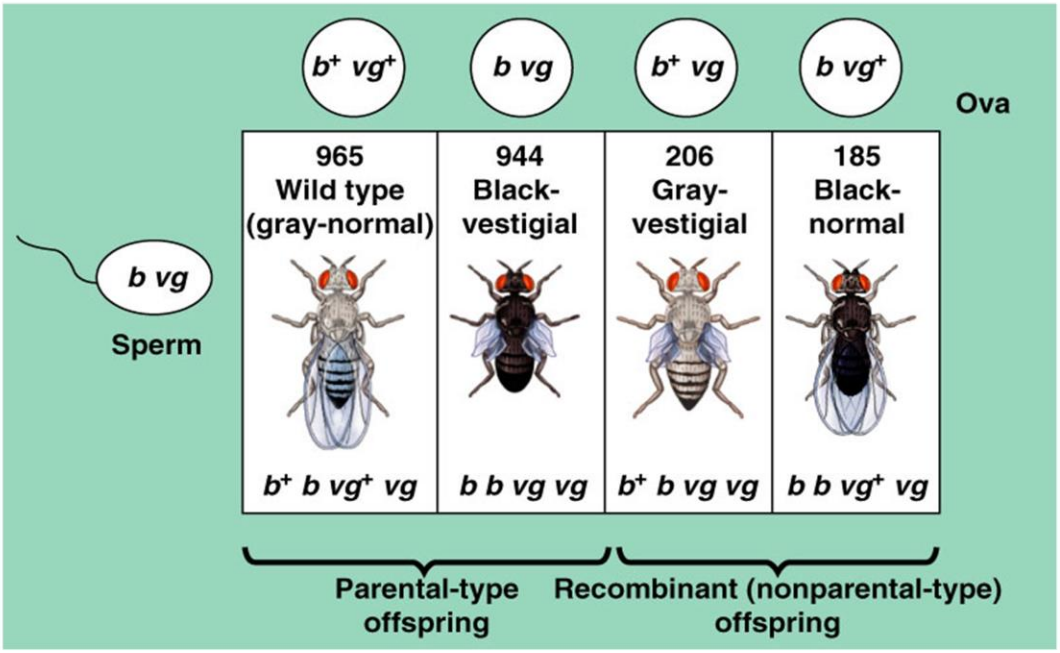
¼ b^+b/vg^+vg (parental)

¼ bb/vg^+vg (recombinant)

¼ bb/vgvg (parental)

¼ $b^+b/vgvg$ (recombinant)

Thomas Hunt Morgan



Actual results deviate from expected results.

Morgan made 2 observations:

1. The **majority** of the offspring appeared like 1 of the 2 parents (They had parental phenotypes. Perhaps these traits were not assorting independently…rather they were dependent on each other. He proposed they may be on the same chromosome, moving as a single unit.

2. **SOME** were "Recombined" (recombinant phenotypes). He proposed that a mechanism can occasionally Un-Link the genes.

Recombination

- Case 1: Recombination of genes that are on different chromosomes (Unlinked).

YyRr (yellow, round) x yyrr (green, wrinkled)

¼ YyRr (yellow, round) ¼ yyrr (green, wrinkled) parental

¼ Yyrr (yellow, wrinkled) ¼ yyRr(green,round) recombinant

½ Parental Pheno. ½ Recombinant Pheno.

Recombination

- Case 2: Recombination of genes that are on the same chromosome (Linked).
- Any number less than 50% means the genes must be on the same chromosome.
- The LOWER the number of recombinants = the CLOSER the genes are to each other.

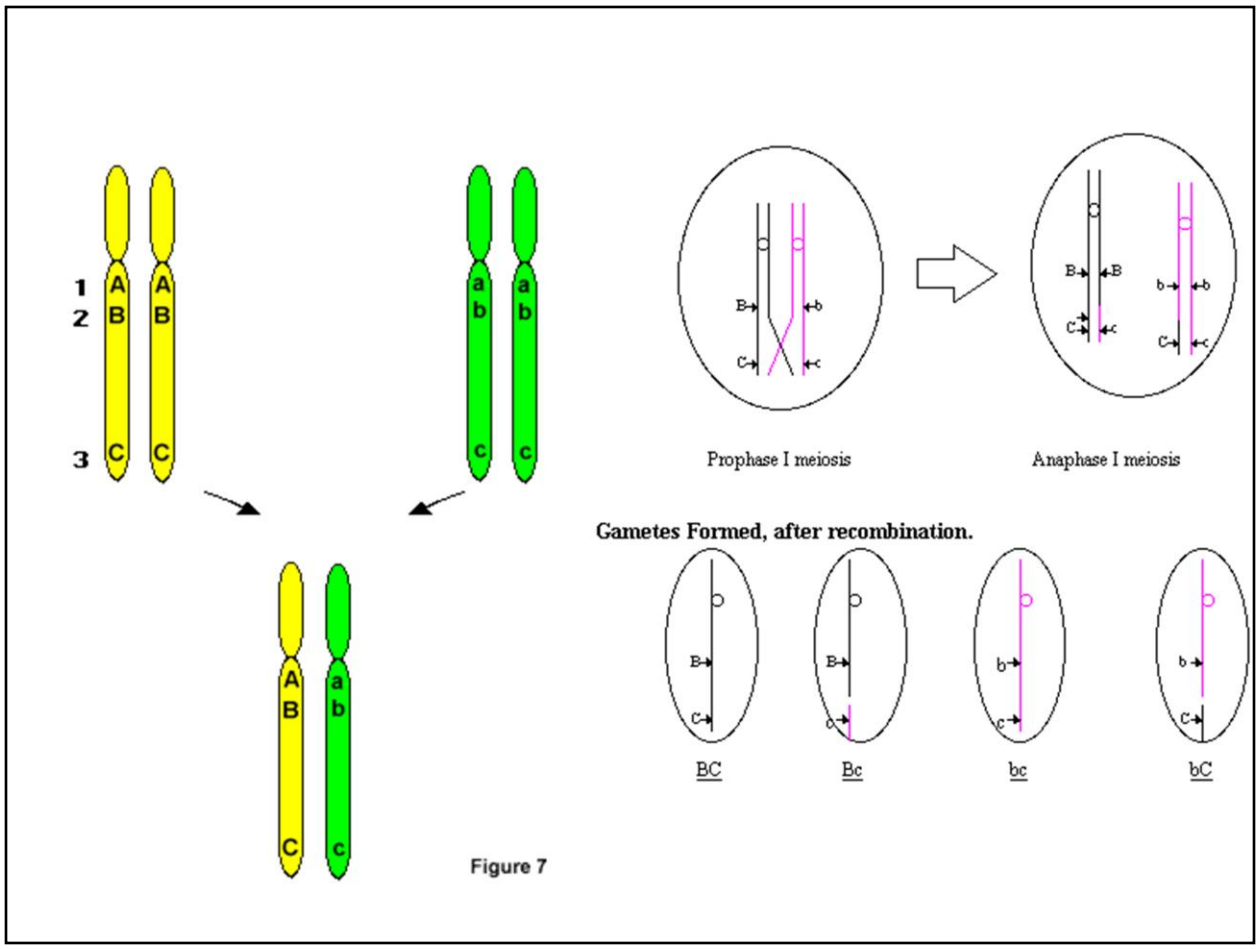


Figure 7

Linked genes can separate if they are far enough away from each other.

In this case, they behave as if they were un-linked.

Genes very close to each other will RARELY separate from crossing over.

In this case, few recombinants would be formed since it is too difficult to break up genes right next to each other.

Recombination

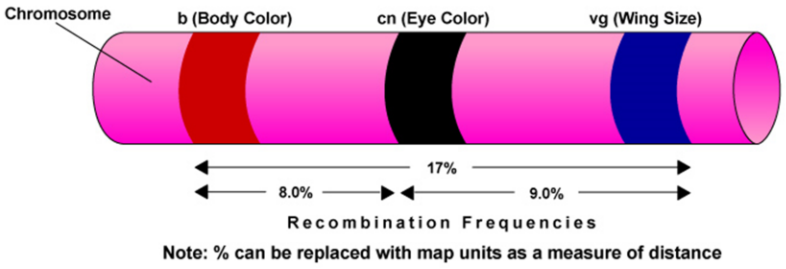
- Equation for calculating recombination Frequencies.
- This is a measure of the distance between 2 linked genes.

Freq. R = # recombinants/ total offspring

Use the data from Morgan's experiment to calculate the recombination frequency, which translates to the distance between the 2 genes.

Gene Mapping

- We can map the locations of genes on chromosomes if we know their recombination frequencies and test different crosses.
- The map units apart with respect to different traits allows us to determine distance & relative directionality.



Note: % can be replaced with map units as a measure of distance

Using the data on the next page, construct a gene map showing the locations between these four genes:

1. Body color (Wild type or Black)
2. Eye Color (Wild type or Purple)
3. Wing Curvature (Wild type or Dumpy)
4. Wing Size (Wild type or Vestigial)

These 4 genes are located on chromosome #2 of the fruit fly *Drosophila* and the wild type phenotype is completely dominant over the other phenotype.

Parent Cross	Offspring Phenotype 1	Offspring Phenotype 2	Offspring Phenotype 3	Offspring Phenotype 4
Wild Type (+ +) X Purple/Black (pb)	280 + +	284 pb	16 p+	20 +b
Wild Type (+ +) X Purple/Dumpy (pd)	176 + +	175 pd	126 p+	123 +d
Wild Type (+ +) X Purple/Vest (pv)	262 + +	263 pv	36 p+	39 +v
Wild Type (+ +) X Black/Vest (bv)	240 + +	249 bv	52 b+	59 +v
Wild Type (+ +) X Black/Dumpy (bd)	193 + +	194 bd	107 b+	106 +d

Using Probability Rules

- Punnett Squares are visuals of mathematical models.
- We can use the rules of multiplication & addition to determine outcomes in many cases.

4 genes in Drosophila located on separate chromosomes are:

Body color – Black or gray (B,b)	Wing size – Normal or vestigial (N,n)
Eye Color – Red or white (R, r)	Bristles – Forked or singed (F, f)

A fly heterozygous for all traits is mated with a fly homozygous dominant for body color & eye color, vestigial wings, & singed bristles.

If the female spawns 250 viable offspring, how many of them would be expected to have the following phenotypes?

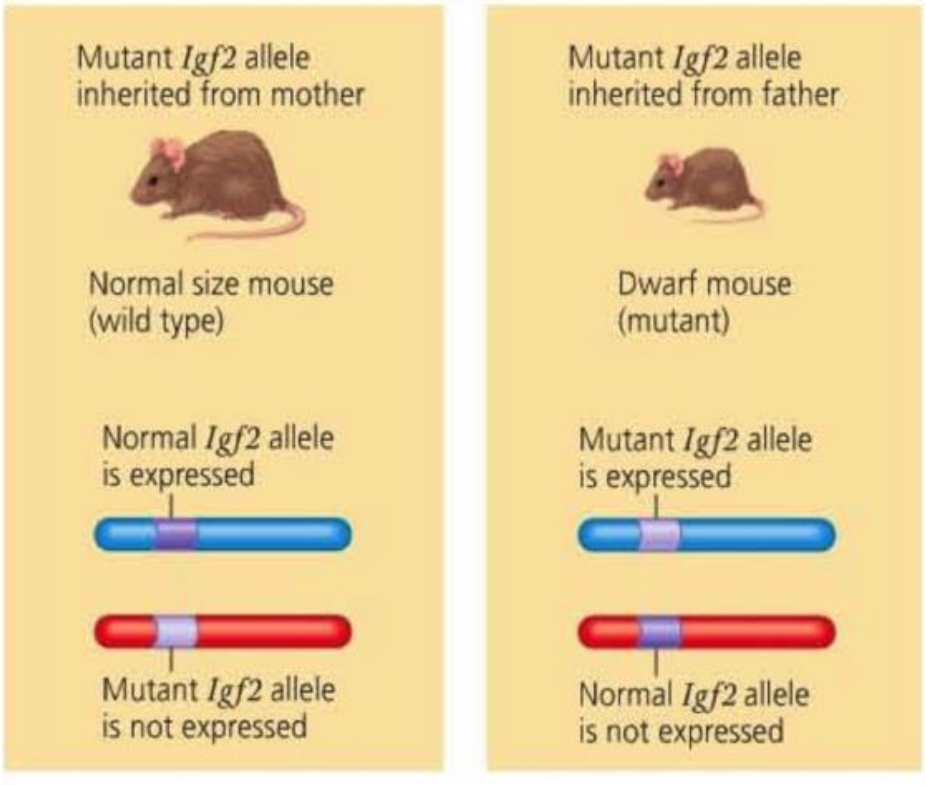
1. Black body, Red eyes, Normal wings & Forked bristles.
2. Gray body, White eyes, Vestigial wings & singed bristles.
3. Vestigial wings or White eyes.
4. Heterozygous for body color & bristles, or has vestigial wings.

Other Patterns of Inheritance

- Mitochondria & Chloroplasts assort completely randomly into new cells.
- Mitochondrial DNA in animals transmitted only from the Ovum – female egg

Genomic Imprinting

The expression of some traits depends on which parent donated the allele. In some cases, the maternal allele is silenced while in others, the paternal allele is silenced. The mechanisms & rationale for these are not currently agreed upon.



Influences on Genes

Polygenic Traits

- Traits that are controlled by a cumulative effect of multiple genes.
  - Eye color & Skin color
    - At least 7 genes vary in degree of pigment darkness
    - Genes combine in a variety of ways.

Epistasis

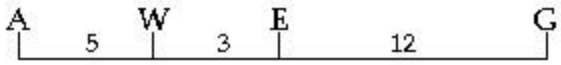
- When the expression of 1 gene affects the phenotype of another gene.
  - Some dog coat colors
    - Gene for pigment deposition
    - Gene for pigment color

Influences on Genes

The Environment

1. Plant height

2. Human weight



The gene map above is of four genes on a chromosome.

1. Between which two genes would you expect the highest frequency of recombination?

A) *A* and *W*

B) *A* and *G*

C) *E* and *W*

D) *A* and *E*

2. Between which two genes would you expect the lowest frequency of recombination?

A) *A* and *W*

B) *A* and *G*

C) *E* and *W*

D) *A* and *E*

3. Suppose that gene "A" codes for the production of keratin protein needed to produce spines in fish and the recessive form results in no keratin production, thus no spines produced. Three separate genes "E", "W" and "G" code for the color of the spines. Which of the following inheritance patterns best describes this scenario.

a. Gene E is epistatic over gene A
b. Gene A is polymorphic over gene E
c. Gene E is polymorphic over gene A
d. Gene A is epistatic over gene E

4. In the same population above, which of the following is likely true?
   a. The genes for spine production is polymorphic
   b. The genes for spine color are polymorphic
   c. The genes for spine color & production are polymorphic
   d. The genes E & W are epistatic over gene G